

A Method of Competition Result Evaluation Based on Social Choice Theory

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Abstract: Competition results are traditionally decided based on referees' rating scores. However, due to the inconsistent evaluation standard and the different subjective wishes of referees, the evaluation results will be affected to some extent. Thus, the objectivity of competition results will be reduced. We propose a method by using referees' preference ordering for players instead of traditional scores to evaluate the competition result. We construct a relationship of referees' preferences for players and calculate players' overall ranking based on social choice theory and group decision. By constructing a directed graph and calculating the value of strongest path, we can improve the objectivity of result evaluation and the difficulty of manipulating competition results. We proved that the proposed method satisfies the criteria of fairness, consistency, maneuverability and monotonicity. Competition results will not be changed due to individual referees' preferences, so we can obtain a more reasonable result. We make a theoretical analysis and a comprehensive experimental study using real datasets to verify the rationality and effectiveness of the proposed method.

Key words: Competition Result Evaluation, Group Decision Method, Social Choice Theory, Preference Ordering

1 INTRODUCTION

In the wake of the rapid economic and social development in China, there have been more and more competitive races emerging in all walks of life. Results of artistic and sport competitions act an important role in measuring the levels of players; and factors influencing on competition results include three aspects: firstly, the fairness of result evaluation mechanism; secondly, the subjective wishes of referees; thirdly, players' performance on the spot.

In traditional competitions, players' scores are decided by referees' evaluation; and the ranking of players' scores are mainly depended on the objectivity of referees and their performance on the sport. Referees' fairness and rationality of scores will directly influence on the place of competitions. In competitions with subjective rating, such as gymnastics, diving and martial art, the traditional method to determine the place is as: the highest and lowest scores are scratched; the average of remaining scores will be players' final scores, which will be ranked as the place of a competition. Such a method can eliminate the influence of excessively high and low scores; yet it fails to change the influence exerted by the subjective wishes of referees on the competition results. Zhao Meilu, et al ^[1] conducted an analysis on parts of competition ranking scores of the 39th Session World Gymnastics Championships and found that

referees' scores featured great difference and random error with inconsistent evaluation standard. The difference of individuals' evaluation will exert significant influences on the objectivity of competition results.

This paper concerns and researches on preference ordering, namely how to generate the overall ranking of players from the different preference orderings of multiple referees. When choosing an optimal player based on competition results, taking referees' preference relationships with players into consideration can upgrade the anti-manipulating capability of the competition. Therefore, considering referees' different evaluation standards, this paper constructs a relationship of referees' preferences for players and calculates players' overall ranking based on social choice theory^[13-14]. This method is good at reducing the maneuverability of traditional competition evaluation method, solving the problem of inconsistent evaluation standards due to referees' subjectivity, for more subjectivity of competition results. This paper firstly introduces some existing methods, which can solve the problem of referees' different evaluation standards; then describes how to utilize social choice function to evaluate competition results in details; in conclusion, this paper proves the fairness, consistency, monotonicity and anti-manipulation of this method via theoretical and empirical analysis.

2 RELATED RESEARCH

During the past years, related scholars and institutions have been making efforts to improve the evaluation rules of competition results. We Dengyun et al ^[2] proposed to use

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“parameter iteration estimation method” to process competition scores and get the estimate of parameters of competition results. Chen Minghua^[3] proposed a method to conduct standardization processing of each referee’s score in advance, summate the processed scores as the final scores, and determine the final ranking based on the final scores. He Jiangchuan^[4] applied nonparametric statistical estimation method to analyze the consistency of each referee’s scores and the entire competition result; score of each referee; then use Kendall’s concordance coefficient to test referees’ entire ranking effect. The abovementioned researches have applied their own methods in various competition result evaluations; those methods have prevented from severe random errors of referees’ scores to some extent; however, the excessive high and low scores of referees still exist, due to their subjective wishes; and the consistency of referees’ evaluation standards is still to be improved.

At present, social choice theory has been widely applied in elections and rankings of multiple fields^[6-7], but fewer in competition evaluation field. Some scholars utilize preference ordering method for group decision-making. In 2013, You Tianhui et al^[5] proposed a decision-making analysis method based on group decision-making problem with multiple indicators of uncertain preference ordering information; based on the basic idea of Bernardo method and uncertain preference information provided by each expert, this method can calculate the related votes and construct the group voting matrix. Schulze^[7] suggested a new monotonous and independent single-winner selection method. Masthoff^[12] constructed a group model and found that TV programs would be ranked differently based on different audience groups. On this basis, it will be of important meaning for competition result evaluation to apply the competition result evaluation method based on social selection theory and reach the entire ranking based on referees’ preference relationships with players.

3 PROBLEM DESCRIPTIONS

Preference ordering is a commonly used technology in social selection commendation, which can fully take advantage of the ordering relation provided by recommenders. For instance, the ordering of two candidates paring ordering; when the number of candidates is more than 2, the method can provide an entire ordering set of players. Compared to paring ordering, the ordering set can be applied in competition result evaluation more effectively.

Prior to discussing the concrete details of social choice arithmetic, we shall introduce some related concepts and symbols in advance.

Def. 1 Referees’ Set is as: $R=\{r_1, r_2, \dots, r_m\}$; players’ set is as: $P=\{p_1, p_2, \dots, p_n\}$.

Due to that there were none competitions evaluated

based on preference ordering, referees’ preference relationships with players can be determined by referees’ scores that are calculated based on players’ comprehensive results in various aspects in the competitions.

Def. 2 The preference of Referee $r_i \in R$ ($i=1, 2, \dots, m$) for Player $p_x, p_y \in P$ ($x, y=1, 2, \dots, n$) is expressed by $s_i(p_x, p_y)$. When $p_x > p_y$, it indicates that Referee r_i believes that player p_x is better than player p_y .

Referees’ preference relationships with players are determined by players’ scores. Due to that it is excessively complicated to calculate each player’s performance result based on a large number of paired preference relationship of each referee, this paper considers to use referees’ overall result orderings as the reference for competition result evaluation. Players’ overall ordering can be obtained through competition result evaluation. Firstly, integrate players history score information into the preference relationships; then compare preference relationships to obtain the overall preference ordering. For instance, when the majority of referees believe p_x is better than p_y , then p_x ’s result evaluation will be higher than that of p_y , and p_x ’s overall ordering will be ahead of p_y .

The definitions of referees’ preference ordering set are as follows:

Def. 3 Referee’ preference ordering set for players is as: $S_i = \{s_i(p_x, p_y) | x, y=1, 2, \dots, n\}$.

Def. 4 Player’s paring preference matrix is as: $= [d(p_x, p_y)]_{n \times n}$, among which $d(p_x, p_y)$ indicates the number of referees who believe p_x is better than p_y . When there is no referee believe that p_x is better than p_y , $d(p_x, p_y)$ equals to 0; when p_x equals to p_y , $d(p_x, p_y)$ is null.

Def. 5 Digraph $G = \langle V, E \rangle$, $V = \{p_1, p_2, \dots, p_n\}$ digraph is player’s nodal set; $E = \{e_1, e_2, \dots, e_k | k \in [n(n-1)/2, n(n-1)]\}$ is directed edge set, and $d(p_x, p_y)$ is set as the weight of the edge between node p_x and p_y .

Def. 6 Strongest path length matrix is $P[p(p_x, p_y)]_{n \times n}$, among which $p(p_x, p_y)$ indicates the length of strongest path from player p_x to p_y . When p_x equals to p_y , $p(p_x, p_y)$ equals to null. $p(p_x, *)$ indicates that strongest path value from p_x to other nodes; $p(*, p_y)$ indicates the strongest path value from other nodes to p_y .

4 COMPETITION RESULT EVALUATION METHOD BASED ON SOCIAL CHOICE THEORY

4.1 Evaluated Result Obtaining

Social choice is a group decision method; it focuses preference of group members then forming groups’ opinion and to develop the right decisions in line with the views of the masses, so chooses social choice theory research competition result evaluation^[15-16]. The preference ordering produce the final ranking list of candidates according to referees’ preference relations to players^[17-18]. Social choice function have a variety of methods, Schulze function is a

better social choice function, it is a preference voting system^[10], and satisfying the majority of Condorcet criterion^[11], compared to other social choice function is more suitable for competition results evaluation, so using Schulze function choice. Schulze function is a voting algorithm proposed with Markus Schulze^[7]. The method can generated overall players ranking results by utilize the referees' preference sort with players.

In this paper, $r_i(p_x, p_y)$ is expressed as the referee r_i vote two players between the p_x and p_y , $p_x >_i p_y$ is denoted as referee r_i indicates that the player p_x is better than p_y , $p_x <_i p_y$ is denoted as referee r_i indicates that the player p_y is better than p_x , $p_x \sim_i p_y$ is denoted as referee r_i indicates there is no different between player p_x and p_y . All $r_i \in R$ ($i = 1, 2, \dots, m$) need to give preference sort set for $p_1, p_2, \dots, p_n$.

$$S_i = \{s_i(p_x, p_y) | x, y = 1, 2, \dots, n\}. \quad (1)$$

Assume $d(p_x, p_y)$ is considered by referee that the number of player p_x is better than p_y . If no one considered that player p_x is better than player p_y , $d(p_x, p_y) = 0$. When p_x is equal to p_y , $d(p_x, p_y)$ is empty.

Construct player's paired preference matrix $D = [d(p_x, p_y)]_{n \times n}$.

Next, construct a weighted directed graph $G = \langle V, E \rangle$.

① If $d(p_x, p_y) > d(p_y, p_x)$,

$$e_i = \langle p_x, p_y \rangle (i = 1, 2, \dots, k) (x, y = 1, 2, \dots, n \text{ 且 } x \neq y) \quad (2)$$

Denote a directed edge from player p_x point to the player p_y , the starting point of the edge is p_x , and the end point of the edge is p_y .

② If $d(p_y, p_x) < d(p_x, p_y)$,

$$e_i = \langle p_y, p_x \rangle (i = 1, 2, \dots, k) (x, y = 1, 2, \dots, n \text{ 且 } x \neq y) \quad (3)$$

Denote a directed edge from the player p_y point to the player p_x , the starting point of the edge is p_y , the end point of the edge is p_x .

③ If $d(p_x, p_y) = d(p_y, p_x)$,

$$e_i = \langle p_x, p_y \rangle (i = 1, 2, \dots, k) (x, y = 1, 2, \dots, n \text{ 且 } x \neq y) \quad (4)$$

Denote as a directed edge from player p_x point to player p_y and player p_y point to player p_x , where p_x, p_y are both side edges of the starting point and the end point.

The essential step of Schulze function is to get the strongest path of two players between p_x and p_y .

The path from player p_x to player p_y is a sequence about players set $p_s, \dots, p_m, \dots, p_e \in P(s, m, e = 1, 2, \dots, n)$, in which p_s is a start players, p_e is an end player, and satisfy the following characteristics:

① $p_s = p_x$

② $p_e = p_y$

③ $1 \leq m \leq n$

④ $\forall m = 1, \dots, (e-1): p_i \neq p_{i+1}$

If there just have only one path can be reached from player p_x to player p_y , then the minimum weight in this path is the strongest path, so the strongest path depends on the strength of its weakest path. Strongest paths $p_x, \dots, p_y$ is

$$p(p_x, p_y) = \min \{(d(p_i, p_{i+1}), d(p_{i+1}, p_i)) | i = 1, \dots, (e-1)\} \quad (5)$$

If there have multiple paths can be reached from player p_x to player p_y , then compared the minimum weight of each path, the maximum value of that path is the strongest path.

$$p(p_x, p_y) = \max \{\min \{(d(p_i, p_{i+1}), d(p_{i+1}, p_i)) | i = 1, \dots, (e-1)\}\} \quad (6)$$

Where in, $d(p_i, p_{i+1})$ denote as the number of referee who consider player p_i better than player p_{i+1} .

Establishing the strongest path matrix $P[p(p_x, p_y)]_{n \times n}$.

Players' score evaluate value is

$$Vp_x = \sum_{k=1}^n (I(p(p_x, p_k) > p(p_k, p_x))) \quad (x = 1, \dots, n) \quad (7)$$

$I(*)$ is a indicate function, and

$$I(p(p_x, p_k) > p(p_k, p_x)) = \begin{cases} 1, & p(p_x, p_k) > p(p_k, p_x) \\ 0, & \text{others} \end{cases} \quad (8)$$

When $p(p_x, p_y)$ is equal to $p(p_y, p_x)$, then calculated the summation respectively of $p(p_x, *)$ and $p(*, p_y)$, Represented by $\text{sum}(p(p_x, *))$ and $\text{sum}(p(*, p_y))$.

① If $\text{sum}(p(p_x, *)) > \text{sum}(p(*, p_y))$, $p(p_x, p_y) > p(p_y, p_x)$.

② If $\text{sum}(p(p_x, *)) < \text{sum}(p(*, p_y))$, $p(p_x, p_y) < p(p_y, p_x)$.

③ If $\text{sum}(p(p_x, *)) = \text{sum}(p(*, p_y))$, $p(p_x, p_y) > p(p_y, p_x)$ or $p(p_x, p_y) < p(p_y, p_x)$ randomly.

As can be seen from (7) to evaluate the results of the competition depends on the quantity of this player's value of strongest path more than others in the same competition. We can get the whole sort of players by compare the each player though the size of result evaluation. In order to prove the result evaluation function suitability in the field of competition, we were verifying the theoretical and experimental respectively. Evaluation method would theoretically analysis and verification in section 3.3.

4.2 Competition Result Evaluation Method based on Social Choice Theory

Based on the analysis mentioned above, we can get the steps for evaluating competition results based on social choice theory:

Step 1 To determine whether there is referees' preference ordering for players; if there is, execute Step 3; if not, execute Step 2.

Step 2 To transfer referees' score data for players into their preference ordering set through Formula (1).

Step 3 To construct player's preference matrix $D = [d(p_x, p_y)]_{n \times n}$.

Step 4 To construct a directed graph as $G=\langle V, E \rangle$ through Formula (2), (3) and (4), according to the paired preference matrix obtained in Step 3.

Step 5 To calculate the strongest path through Formula (5) and (6), based on the digraph obtained in Step 4.

Step 6 To generate the strongest path length matrix $P[p(p_x, p_y)]_{n \times n}$.

Step 7 To get player's evaluated result according to Formula (7).

Step 8 To make an entire ordering of players based on evaluated results.

4.3 Theoretical Analysis of Evaluation Model

This section will utilize Schulze function to prove the fairness, consistency, monotonicity and anti-manipulation of competition result ordering.

Principle 1 (Fairness) For any player p_x or p_y , when each referee believes that $p_x > p_y$ and $p(p_x, p_y) > p(p_y, p_x)$, then $p_x > p_y$ in the entire ordering; when each referee believes that $p_y > p_x$, then $d(p_y, p_x) > d(p_x, p_y)$ and $p(p_y, p_x) > p(p_x, p_y)$, and $p_y > p_x$ in the entire ordering.

Demonstration. $d(p_x, p_y)$ indicates the number of referees who believe p_x is better than p_y . Given that a referee believes that $p_x > p_y$, then it is obvious that $d(p_y, p_x) > d(p_x, p_y)$. Therefore, according to Formula (5) and (6), $p(p_x, p_y) > p(p_y, p_x)$. Similarly, when each referee believes $p_y > p_x$ and $d(p_y, p_x) > d(p_x, p_y)$, then $p(p_y, p_x) > p(p_x, p_y)$ and $p_y > p_x$.

Principle 2 (Monotonicity) When referees' preferences are unchanged and their entire ordering for any player p_x and p_y and p_z is as $p_x > p_y > p_z$, if a certain referee upgrades his/her score for p_y , then the ordering of p_y compared to p_x and p_z will be unchanged or move ahead, featuring monotonicity.

Demonstration. When referees' preferences are unchanged, and the entire ordering result for any player as p_x, p_y and p_z , there shall be a ordering that $p(p_x, p_y) > p(p_y, p_x)$, $p(p_x, p_z) > p(p_z, p_x)$ and $p(p_y, p_z) > p(p_z, p_y)$. According to Formula (5) and (6), if $d(p_x, p_y)$ is increased, $p(p_x, p_y)$ will not be reduced, so that when the number of referees who believe p_y is better than p_z and p_x is increased, $p(p_x, p_z) > p(p_z, p_x)$ and $p(p_y, p_z) > p(p_z, p_y)$ are unchanged, with $p(p_x, p_y) > p(p_y, p_x)$ and $p(p_y, p_x) > p(p_x, p_y)$, namely the entire ordering is adjusted as $p_y > p_x > p_z$, or maintains the ordering as $p_x > p_y > p_z$, due to monotonicity.

Principle 3 (Consistency) For any player as p_x and p_y , when all of users believe $p_x > p_y$, then $p(p_x, p_y) > p(p_y, p_x)$, namely when the strongest path value of p_x is higher than that of p_y , the consistency can be satisfied.

Demonstration. When all of referees believe $p_x > p_y$, it is obvious that $d(p_x, p_y) > d(p_y, p_x)$, namely the result is $p_x > p_y$, which satisfies consistency, among which $d(p_x, p_y)$ indicates the number of referees who believe p_x is better than p_y ; and $p(p_x, p_y)$ indicates the strongest path value from player p_x to p_y .

Principle 4 (Anti-manipulation) The change of weighted value on the path between p_x and p_y will change the final ordering of p_x and p_y , and may also change the orderings or other players.

Demonstration. The change of $d(p_x, p_y)$, weight of individual path in the weighted digraph will not only change the strongest path between two players p_x and p_y on this path, but also change the strongest path value between other players shown in Formula (6) and other players orderings. Therefore, the change of weights on specific paths can't manipulate any players' ordering; the calculation of play ordering based on weighted digraph has improved the difficulty of ordering manipulation.

5 EXPERIMENT & ANALYSIS

Based on the social choice method mentioned above, this paper verifies the evaluation data. Through verifying the fairness, consistency, monotonicity and anti-manipulation of players' scores based on referees' preferences, the experiment has proved the effectiveness and rationality of social choice method. Traditionally, competitions are only scored without preference ordering, so that the experiment could only use the preferences demonstrated in scores as sample data.

The experiment data are provided by literature [1] about various individual competition data set of 39th Session of World Gymnastics Championships. Data set G1 indicates the score data of Women's Uneven Bars Finale; data set G2 indicates the score data of Men's Horizontal Bar Finale; data set G3 indicates the score data of Men's Rings Finale. All of competitions were equipped with 6 referees and 8 players. The experimental environment is PC, with OS as Window 7, processor as Core(TM) i3-4150 and RAM as 8GB.

In order to better verify the effectiveness of method, this paper obtains players' scores marked by each referee based on sample data; and it is obvious that the scores are non-interfering. Then, this paper applies preference ordering method to obtain each referee's entire ordering of all of players; it is obvious that the ordering is clear and unique. Then, this paper calculates each referee's scores for all of players through regular competition score method, e.g. the data set of World Gymnastics Championships applied in this paper, with each referee sharing equal rights. In order to verify the effectiveness in competition result evaluation, this paper conducts the following experiments on fairness, monotonicity, consistency and anti-manipulation.

5.1 Fairness

This paper use Schulze function to calculate the score evaluations of data set G1, G2 and G3, to get the entire ordering of players. In order to verify the fairness of this method, this paper gets the inverse values of each referee's

scores for all of players, namely the inversed preference

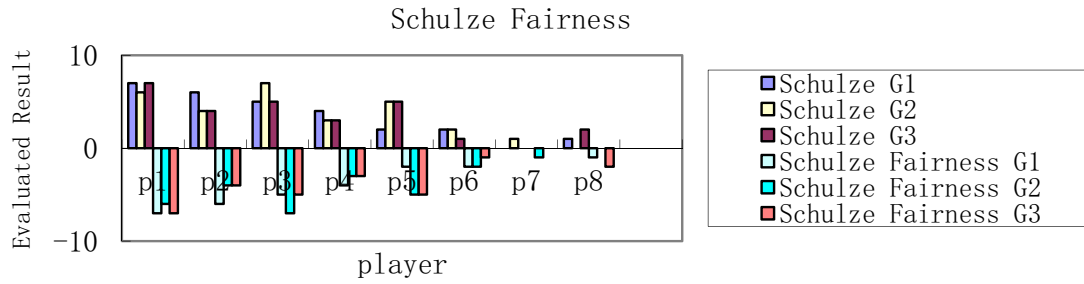
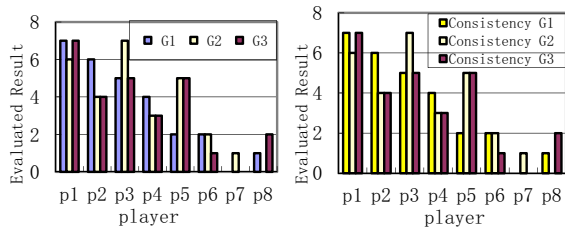


Fig 1. Fairness Verification

relationship; then, use Schulze function to recalculate and get the inverse ordering. In Graph 1, the space above the horizontal axis includes the evaluated results based on Schulze function; the space below the horizontal axis includes the inversed results of referee's scores. The experiment has shown that if a referee makes an inverse choice, then the entire ordering will be inversed, demonstrating that this method is fair for players. The entire orderings under normal situation are as G1: $p_1 > p_2 > p_3 > p_4 > p_6 > p_5 > p_8 > p_7$; G2: $p_3 > p_1 > p_5 > p_2 > p_4 > p_6 > p_7 > p_8$; G3: $p_1 > p_3 > p_5 > p_2 > p_4 > p_8 > p_6 > p_7$; after using referees' inversed preference relationships with players, the entire orderings of players are as: G1: $p_1 < p_2 < p_3 < p_4 < p_6 < p_5 < p_8 < p_7$; G2: $p_3 < p_1 < p_5 < p_2 < p_4 < p_6 < p_7 < p_8$; G3: $p_1 < p_3 < p_5 < p_2 < p_4 < p_8 < p_6 < p_7$.

5.2 Consistency

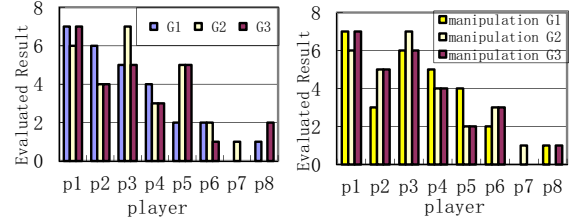
When all of referees believe that player p_x is better than p_y , then the final evaluated result will be $p_x > p_y$, showing that this method features consistency. In order to verify the consistency of group ordering, this paper changes the number of referees in data set G1 who believe that player p_1 is better than p_3 into 6, the number of referees in data set G2 who believe that player p_1 is better than p_2 into 6, and the number of referees in data set G3 who believe that player p_1 is better than p_3 into 6. Similarly, this paper utilizes Schulze function to calculate the evaluated results as shown in Graph 2. The entire orderings of final data sets are as: G1: $p_1 > p_2 > p_3 > p_4 > p_6 > p_5 > p_8 > p_7$; G2: $p_3 > p_1 > p_5 > p_2 > p_4 > p_6 > p_7 > p_8$; G3: $p_1 > p_3 > p_5 > p_2 > p_4 > p_8 > p_6 > p_7$. The results have shown that in the final results of G1, $p_1 > p_3$; in G2, $p_1 > p_2$; and in G3, $p_1 > p_3$; this has verified the consistency of this method.



(a) Schulze Function (b) Consistency Schulze Function
Fig 2. Consistency Verification

5.3 Monotonicity

In order to verify the monotonicity of the entire ordering, this paper selects a path randomly and upgrades its weight, to judge whether the ordering of players on this path is changed. If the place of this player is ahead or unchanged, then the monotonicity of this method is verified. The experiment selects player p_1 as the example and upgrades the weighted value of path of p_1 directing to p_2 in G1, G2 and G3. The results has shown in Graph 3(b) that the final entire ordering are as: G1: $p_1 > p_2 > p_3 > p_4 > p_6 > p_5 > p_8 > p_7$; G2: $p_3 > p_1 > p_5 > p_2 > p_4 > p_6 > p_7 > p_8$; G3: $p_1 > p_3 > p_5 > p_2 > p_4 > p_8 > p_6 > p_7$. The orderings of p_1 in G1, G2 and G3 are still ahead of p_2 , verifying the monotonicity of this method.

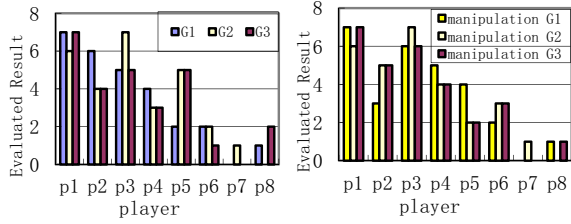


(a) Schulze Function (b) Monotonicity Schulze Function
Fig 3. Monotonicity Verification

5.4 Anti-manipulation

The change of $d(p_x, p_y)$, weighted value of individual path on weighted digraph, will not only change the strongest path between player p_x and p_y on this path, but also change the strongest path values and ordering of other players, according to Formula (2). Taking player p_5 as an instance, through increasing the weighted value of p_5 -directing-to- p_2 -path in G1, the weighted value of p_6 -directing-to- p_5 -path in G2 and the weighted value of p_6 -directing-to- p_5 -path in G3, we can get the evaluated results of players as shown in Graph 4(b). The final entire ordering are as: G1: $p_1 > p_3 > p_4 > p_5 > p_2 > p_6 > p_8 > p_7$; G2: $p_3 > p_1 > p_2 > p_4 > p_6 > p_5 > p_7 > p_8$; G3: $p_1 > p_3 > p_2 > p_4 > p_6 > p_5 > p_8 > p_7$. This has shown that the change of weighted value on specific path will not only change the ordering of two players on this path, but also the ordering of other players, so that it is impossible to manipulate the ordering of players by changing the weighted values on specific path. Thus, the

anti-manipulation of this method has been verified.



(a)Schulze Function (b)Manipulation Schulze Function
Fig 4. Manipulation Verification

6 CONCLUSION

This paper studies the method of completion result evaluation based on social choice theory, which obtains the ordering of players based on referees' subjective wishes. This method firstly transfers the scores in traditional competitions into referees' reference ordering for players through calculation; then uses Schulze function in social choice theory to get the evaluation of players' scores; then applies theoretical analysis and experiment to verify the fairness, monotonicity and anti-manipulation of this method and verify the effectiveness of this method for players' scores. This method based on social selection theory can obtain better effect as mentioned in the experiment above; however, due to the fewer experiment procedures, fewer time of competitions and limited varieties in the sample, there are a lot of experiments in need for further verification in the future. The method based on preference ordering aims at traditional subjective competitions, not applying to non-subjective competitions. There are a lot of factors that may influence on the result of a competition; in the future, researches on competition objectivity shall be conducted while taking other information into consideration on this basis, e.g. referees' level and players' on-the-spot performance, in order to upgrade the feasibility of this method.

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